DeepGreen

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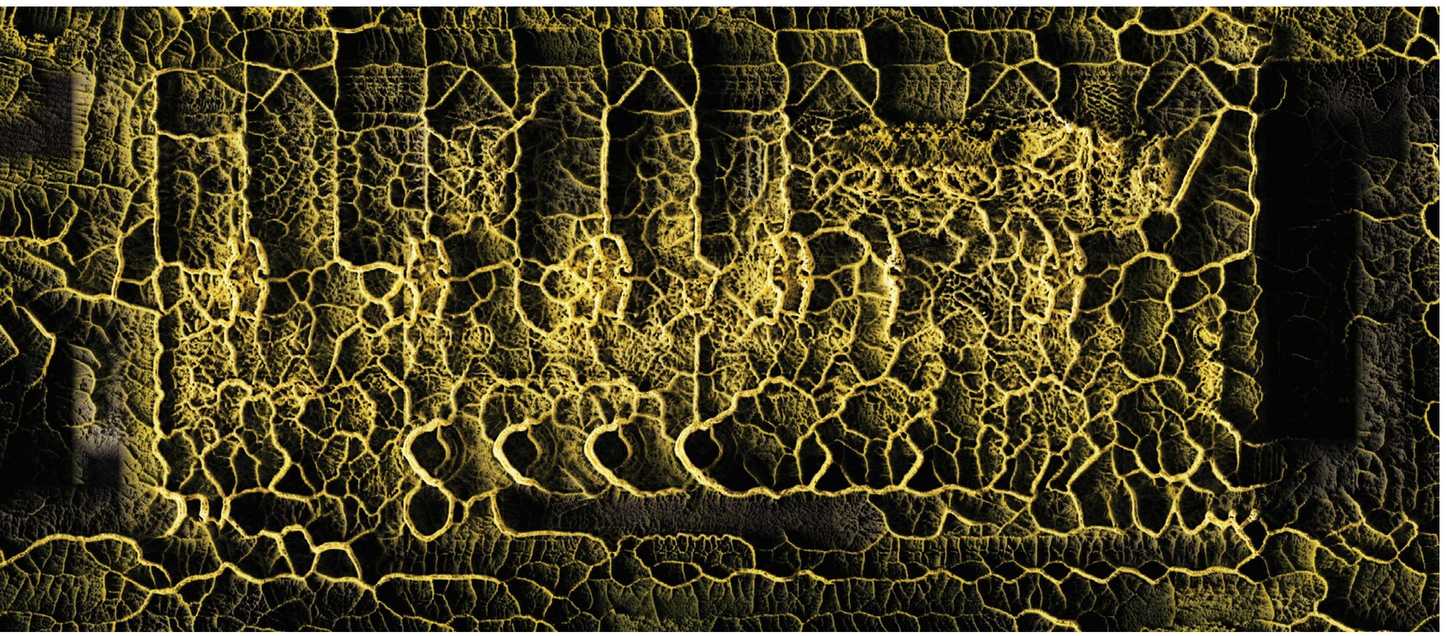
Coupling biological and Artificial Intelligence in Urban Design



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1 Translation of the Centre Pompidou based on the GAN_ Physarum algorithm

ABSTRACT

Ubiquitous computing enables us to decipher the Biosphere's anthropogenic dimension, what the authors call the Urbansphere (Pasquero, Poletto, 2020). This machinic perspective unveils a new post-anthropocentric reality, where the impact of artificial systems on the natural Biosphere is indeed global, but their agency is no longer entirely human.

This paper explores a protocol to design the Urbansphere, or what we may call the urbanisation of the non-human, titled DeepGreen. With the development of DeepGreen the authors and their team are testing the potential to bring at the core of architectural and urban design research the interdependence of digital and biological intelligence.

This is achieved by developing a new bio-computational design workflow that enables pairing what is algorithmically drawn with what is biologically grown (Pasquero, Poletto, 2016). In other words, and more in detail, the paper will illustrate how GAN (Generative Adversarial Networks) algorithms (Radford et al. 2015) can be trained to "behave" like a Physarum Polycephalum, an unicellular organism endowed with surprising computational abilities and self-organizing behaviours that have made it popular among scientist and engineers alike (Adamatzky, 2010). (Fig.1)

The trained GAN_Physarum is deployed as an urban design technique, to test the potential of Polyclephalum intelligence in solving problems of urban re-metabolisation and in computing scenarios of urban morphogenesis within a non-human conceptual framework.

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Developing a bio-digital design workflow

Learning how to interpret large remote sensing data sets from the unique perspective granted by GAN_Physarum, enables a deeper enquiry into the contemporary significance of traditional planning concepts such as zone, boundary, scale, typology and program. (Fig.2)

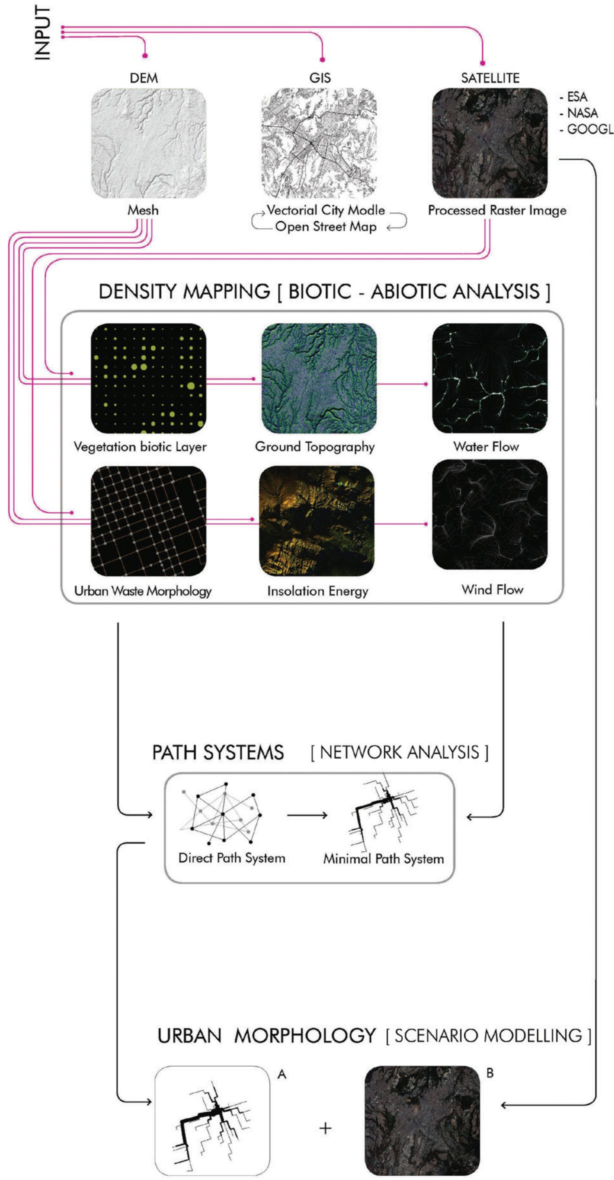
This process introduces new spatial metrics to measure cities' self-sufficiency, valuing what economists call "externalities" towards other societal and ecological systems (Mazzuccato, 2017). A specific bio- computational design workflow generates consistent training datasets for GAN_ Physarum, and this paper illustrates the authors' efforts in that regard. The workflow includes four main levels of computation. Input data reading, biotic-abiotic analysis, network analysis and finally scenario modelling.

For the first level analysis, advanced algorithmic design techniques are used in order to read large data sets from satellite, GIS and Digital Elevation Model sources (Pasquero, Poletto, 2017). Level2 and 3 recognize and analyse the morphology of the city, the surrounding landscape and the resources' networks. The analysis produces density maps and path systems for several urban systems such as biomass, water collection, solar energy, community waste and so on. These maps become training datasets for GAN_Physarum.

Setting up a test bed for DeepGreen

The paper illustrates a number of applications of this approach to real case studies. In particular within the framework of ecoLogicStudio's ongoing cultural collaboration with the Centre Pompidou in Paris, and with partner cities, within the framework of the United Nations Development Programme (UNDP innovation facility funding and City Experiment Fund). The aim of these case studies is twofold: to speculate on the significance of a non-human design framework on the re-conception of an heavily planned city such as Paris, and, consequently to provide local communities, cities and governments with the most advanced toolset to reprogram global cities for a safer and healthier post-pandemic world.

Ultimately with the integrated use of remote sensing, big data analysis and Artificial Intelligence, DeepGreen can be deployed to assess urban vulnerabilities and find specific urban design solutions to achieve immediate and long-lasting impact (Fig.3, 4). Through these case studies, the authors speculate on the possibility for a general



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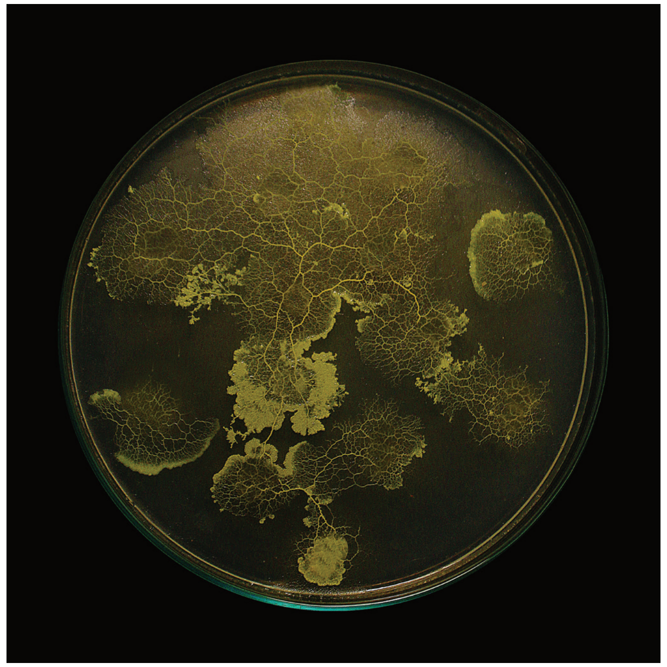
2 Flow Diagram describing the process in Guatemala City; proposal based on algorithms, driven by bio-artificial intelligence.

3,4 Redefined morphology of networks in the city of Guatemala City ; proposal based on bio-artificial intelligence algorithms.



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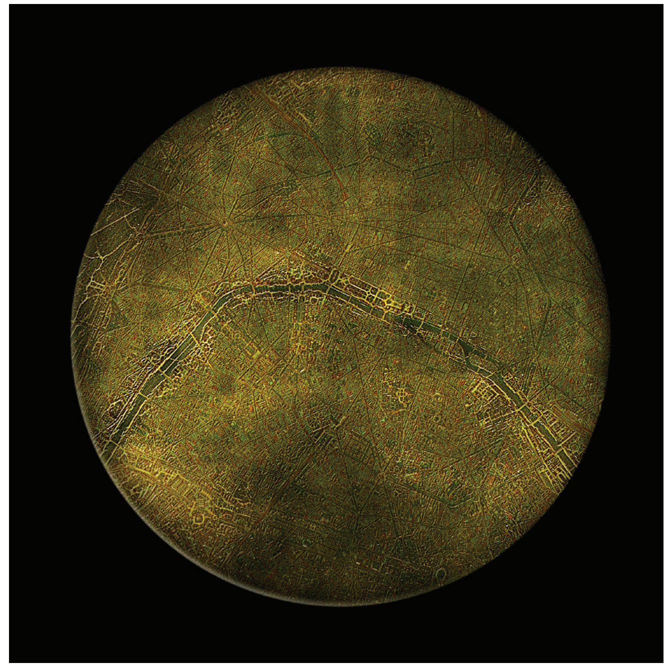

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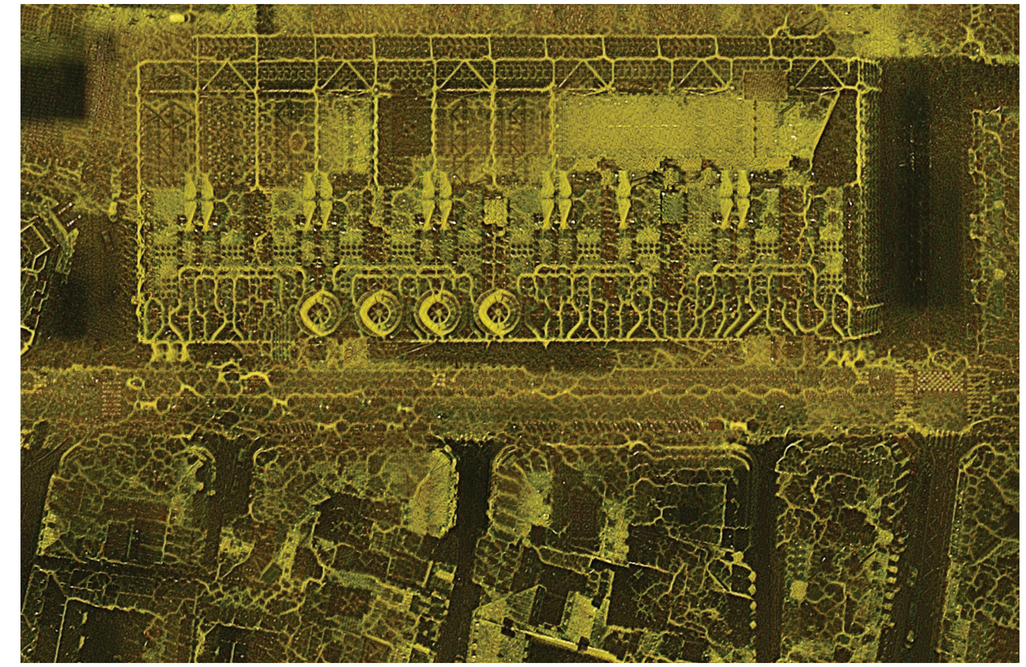

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5 Physarum Polycephalum as biological computer

6 GAN_Physarum 10by10 km Frame - Paris Iteration

7 GAN_Physarum 100by100meters Frame - Centre Pompidou Iteration

applicability of the DeepGreen protocol, its scalability and possible widespread adoption. This speculation provides a critical assessment of the current paradigm of urban green planning and the conceptual and practical significance of urban re-greening in the current, crisis-ridden, post-anthropocentric, reality.

Training and testing GAN_Physarum

cycleGAN algorithms belong to the class of machine learning frameworks (Zhu et al. 2017). They involve an automatic unsupervised training of image-to-image translation models without paired examples. In this case, the domain of sources images and target images refer to the slices of two actual input-images that belong into two different domains, the urban and the biological. cycleGAN algorithms are deployed at level four of the overall DeepGreen workflow and the process can be further divided in four phases for clearer illustration.

The first phase describes the preparation of the input images deployed to train GAN_Physarum. The second phase is the training of the algorithm based on these input-datasets. The model is trained to detect the urban morphology of case study cities and the biological growth patterns of Physarum Polycephalum. During training the algorithm typically runs 200 epochs, or iterations, over which it self-improves.

At this stage, the models are sufficient for generating plausible slices in the target domain but are not translations of the input slice. This occurs in the third phase, the testing phase, during which the algorithm translates the bio-computational patterns onto the cases study city.

In the fourth phase all resultant tiles are recombined and the final output image is recreated. This can produce true colour satellite visions of the case study, its urban morphology and serval testing scenarios for the integration of biotic and abiotic systems within the urban landscape.

The case of Paris

To illustrate this protocol in action the GAN-Physarum is sent on a computational derive on the streets of Paris (Debord, 1956). While at first the visions conjured by GAN-Physarum have the disorienting quality of the non-human mind that conceived them, they also connect us with contemporary Paris at a more fundamental systemic level. (Fig.5-7)

It is in fact known that contemporary cities share unique emergent behaviours and self-organizing growth patterns with organisms like Physarum Polycephalum (Tero et al. 2010). Transport networks are ubiquitous in both urban and biological systems. Robust network performance involves a complex trade-off involving cost, transport efficiency, and fault tolerance. Biological networks have been honed by many cycles of evolutionary selection pressure and they develop without centralized control. This represents a readily scalable solution for growing networks in general and as part of a complex urban system. Therefore GAN_Physarum has the potential to evolve into a resilient urban planning model.

When the trained GAN_Physarum is deployed it actualises the capacities of Physarum Polyclephalum in solving problems of urban re-metabolisation, carbon neutrality, energetic self-sufficiency and increased biodiversity. Most importantly these ambitious objectives are tackled within a non-human conceptual framework therefore opening up a whole new palette of potential design solutions in the urban realm. GAN_Physarum, in other words, offers the prospect of avoiding some of the common pitfalls of biophilic and biomimetic design protocols, namely the need for all too human metaphorical interpretations, as in the case of "urban forests", or reductionist abstractions, as found in most "green networks" proposals.

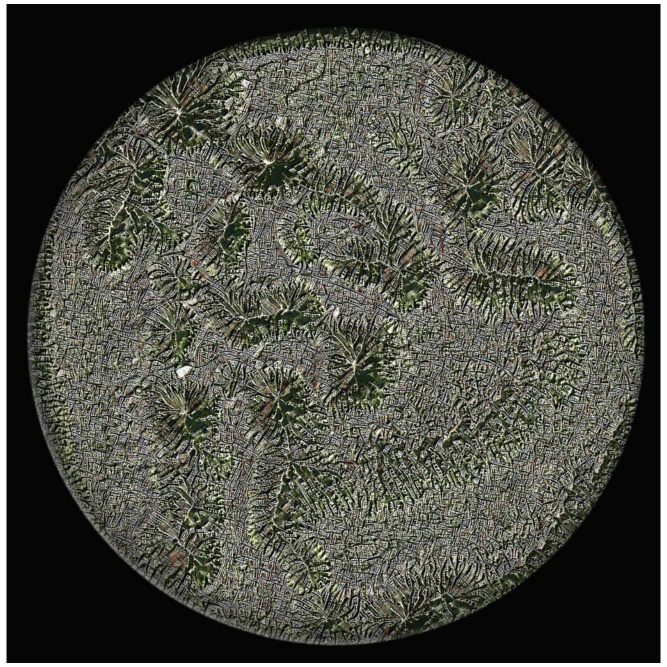
Following the typically distributed model of practicing research in the global pandemic reality of 2020, the Parisian derive of GAN-Physarum starts in the air conditioned laboratories of the Synthetic Landscape Lab at University of Innsbruck. Here at a constant room temperature of 20 degrees a living Physarum Polycephalum in its active plasmodium phase is made to hunt for nutrients within the sterile environment of a lab grade borosilicate glass Petri dish. Initially the growth substratum consists of a 2% Agar with oat flakes as locally condensed food sources.

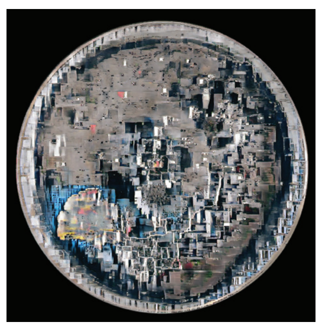
The plasmodium's typical networked body began spreading within minutes. For better documentation the Petri dish is positioned on a backlit surface and a camera is held above by a tripod. The camera lens has a focal length of 50mm and the resolution of the raw images is 4240 x 2832 pixels. One photo is taken each 60 seconds for a total of 5190 images. The typical experiment lasts for approximately 3 days and half.

The frames are then further edited by inverting the original input image and then copy the original layer on top with the blend mode colour filter. For further clarity of detail a drop of blue food colouring is added on the agar substratum.

Once combined into a video sequence these frames reveal the extraordinary morphogenetic process during which Physarum Polycephalum's body transforms into an optimised network for nutrients distribution. The process starts with a searching phase during which the pulsating body branches out in all direction detecting food sources and their relative distribution and size. In this phase traces of actin are left on the substratum, constituting a form of embedded memory, Physarum Polycephalum's own outsourced brain.

What follows is a phase of optimisation. Finely detailed branches emerge in the relevant areas of the Petri while other parts are abandoned. Eventually some of the branches grow in size and become thickening convoluted transportation arteries. However the optimized configuration never settles. As the resources are consumed and their overall distribution changes in real-time, Physarum Polycephalum's morphology adjusts.





8 Transformation of Paris based on the biological intelligence of the Physarum using the GAN_Physarum algorithm

9 GAN_Physarum algorithm applied on a 10x10m scale: Centre Pompidou Roof

10 GAN_Physarum algorithm applied on a 100x100m scale: Centre Pompidou

The scarcer the resources become the more accelerated the change and adaptation. At the tipping point Physarum Polycephalum is seen racing around the Petri in an attempt to find new sources with sufficient energy to sustain its searching effort. Once nothing is left it retreats, until all the remaining energies are deployed to create new fruiting bodies, thus commencing the next phase in Physarum Polycephalum's uniquely elaborated like cycle. After several years of experimentation it still beggars the authors' belief how so much complexity of form and behaviours can emerge from a simple unicellular organism.

Over time, the authors and their research team have increased the complexity of the nutrients' mix. The PH of the nutrients is now controlled to maintain high values. A selective distribution of malt extracts, oats and Spirulina powder extracts is now precisely inoculated to act as attractor points while a triple biotic ointment works as repellor. Through this system of nutrients distribution the research team can now directly "communicate" with, or transfer information to, the Physarum Polycephalum.

A satellite image of Paris, duly processed to extract information about its biotic layer (plants, grasses, rivers and other "wet" surfaces), is remapped on a grid. The points on the grid transfer the geo-data of corresponding latitude and longitude of the map. A 3D data matrix is compiled storing the density of biomass as a percentage value of a fully vegetated pixel. This is achieved by translating the sum value of the green pixels of the map for each 4 neighbouring cells within the grid to an average percentage based on the total value of all the green pixels of the selected image.

After computing the average biomass on the grid points, these percentages of density are translated proportionally into amounts of nutrients on the growth substratum of Physarum Polycephalum, with cell size of 3cm. Physarum Polycephalum is then introduced from a source point external to the grid. And while Physarum Polycephalum begins its long bio-computational process to define the spatio-temporal distribution of nutrients, the authors and their team can shift their attention to the machine learning technique Cycle GAN, and in order to refine its ability to detect the biologically grown characteristics of Physarum Polycephalum and its complex behavioural patterns.

GAN_Physarum: "La Derive Numerique"

CycleGAN is a machine learning technique that uses the training of image to image translation models without paired examples. A generative adversarial network (GAN) has two parts, the generator and the discriminator, engaged in an internal competition. The generator learns to generate plausible data. The generated instances become negative training examples for the discriminator. The discriminator learns to distinguish the generator's fake data from real data. The discriminator penalizes the generator for producing implausible results. (Google Developers, 2019)

Depending on the training input, this process results in the transfer of key features from one set of images onto another, and vice versa. In this case, the domain of sources images and target images refer to the slices of two actual input-images that belong into two different domains, the urban and the biological. We used this technique to transfer the behavioural patterns of the Physarum Polycephalum onto the urban structure of Paris. The objective is to investigate how its biological intelligence can be applied on different scales to reinterpret existing infrastructures and building distributions of Paris itself.

11 GAN_Physaruma algorithm applied on a 1x1km scale

12 GAN_Physarum algorithm applied on a 10x10km scale

While time lapsing, as described above, captures Physarum Polycephalum at different developmental stages, Paris is analysed at different resolutions thought remote sensing. The significance of adding a zero to any number (Eames, 1977) reveals itself as a multiplicity of urban structures and urban morphological patterns can be detected as visual information while zooming in on the Centre Pompidou from a wide frame including the entire centre of Paris. (Fig.8-12)

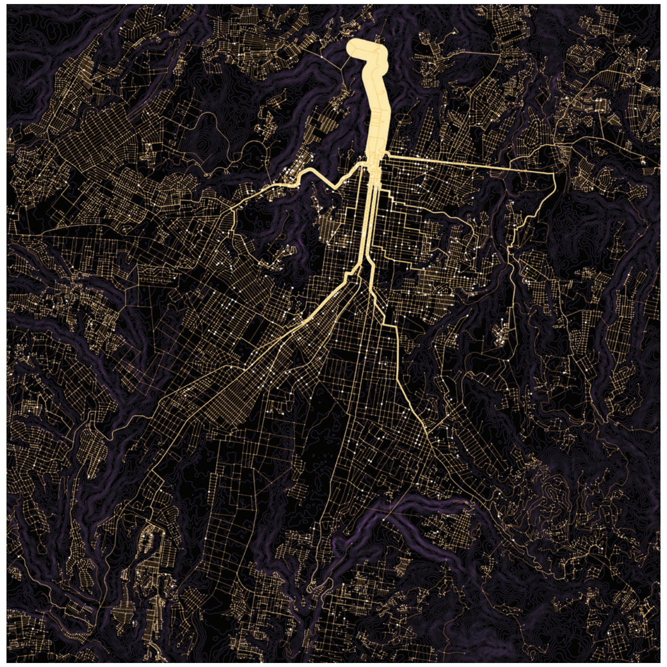
By using the power of ten as decreasing degree of magnitude, the protocol captures frames of Paris at 4 different resolutions. The largest city scale is a 10 by 10 km frame, including the entire circular Périphérique of Paris and centred on the site of the Centre Pompidou. While zooming in, further resolutions are registered, including a 1 by 1 km frame, showing the Centre Pompidou with its surrounding neighbourhood, a 100 by 100m frame, representing the structure of the Centre Pompidou with the adjacent streets and squares, and finally, a 10 by 10 m frame, focussing on the mechanical systems forming the external envelope of the celebrated Parisian architectural machine.

The machine learning algorithm of GAN_Physarum is trained at each of these urban resolutions to a corresponding behavioural pattern of Physarum Polycephalum.

The algorithm learns to interpret Paris in a unique way at each resolution. During the training process the characteristics of the Physarum Polycephalum behavioural patterns are compared to the ones of Paris. Over several epochs the algorithm learns how to reinterpret Physarum Polycephalum's behaviours in relationship to Paris' morphological structures, and vice versa. When several behavioural instances are tested and the results are combined in a video sequence, a bio-digital derive emerges, and with it an unexpected vision of Paris coming alive in the mind of GAN_Physarum.

This non-human cognitive process is underpinned by the GAN_Physarum Workflow developed by the authors and their team. It can be described in four main phases:

- the first phase describes the preparation of the input images for training purposes. The dataset preparation is automated, slicing input images from both time-lapse and satellite source domains into equal tiles of 256 x 256 pixels in size. This phase also includes pre-processing the input data with custom colours and contrast adjustments. Such adjustments increase the recognisability of the distribution of detected structures in the satellite source in relationship to the biological one.



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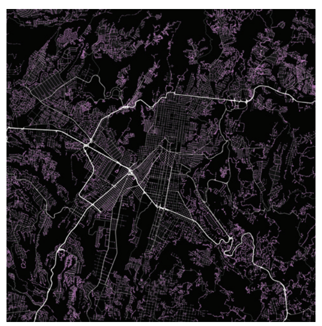

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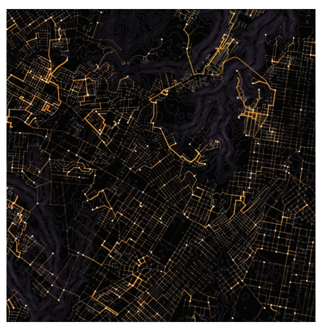

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13 Local to municipal waste collection networks in the city of Guatemala. Image algorithmically computed from GIS map, satellite map and DEM model analysis by means of minimal path algorithm. The analysis also takes into account the result of the local waste collection analysis. Iteration 1

14 path system and network in the city of Guatemala. Image algorithmically computed from GIS map, satellite map and DEM model analysis by means of minimal path algorithm.

15 community waste collection networks in the city of Guatemala. Image algorithmically computed from GIS map, satellite map and DEM model analysis by means of minimal path algorithm.

• The second phase is the training of the GAN_Physarum based on these input datasets. The model is trained to detect the structures in the satellite source in relationship to the biological one, so it can learn to project behavioural patterns to urban morphologies. During the training the algorithm runs 200 epochs and the visualization of the evolutions can be illustrated in a browser window showing the learning process (loss function) of the algorithm.

• At this stage the model is sufficient for generating plausible slices in the target domain. Subsequently the trained algorithm is tested. During this phase, the GAN_Physarum projects an input image in the biological domain A to an image in the urban domain B, and vice versa. Several cached models from the training phase can be loaded at this stage, thus tracking the self-evolution of GAN_Physarum.

• The fourth and final phase in the GAN_Physarum workflow refers to the combination of the output slices. This process is also automated. The algorithm uses the resulting output tiles from the testing algorithm, and combines them to a final image, using an overlap between the image tiles to get clean transitions in the combined output image.

Just like Physarum Polycephalum cities are dynamical systems that react to a variety of external resources' distributions and adapt by changing their morphology over time. They both undergo constant transformations to optimize their overall performance. This aspect of transformation over time is accounted for in GAN_Physarum. This however requires multiple training sessions at each scalar resolution, since every scale has different structures of detail that can be interpreted. This is the case for both Paris and Physarum Polycephalum. This process offers an unprecedented opportunity for a holistic analysis of the relationship between urban patterns and biological intelligence. Such analysis has widespread application. In order to validate such assumption, and test the scalability of the GAN_Physarum protocol, the authors and their practice ecoLogicStudio have partnered with UNDP on a dedicated research project titled DeepGreen.

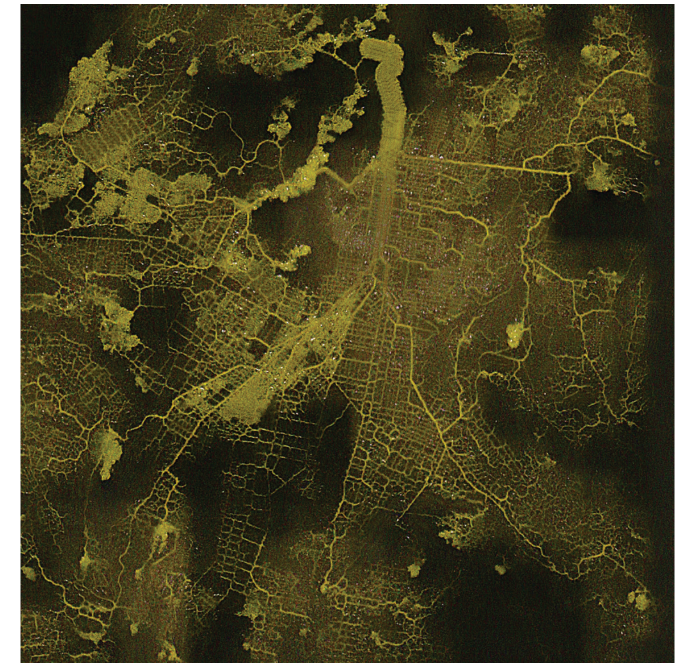
DeepGreen, the case of Guatemala City

In this project the authors have been testing the applicability of the GAN_Physarum workflow as a green planning interface. Its key feature is to combine scalability, a necessary quality of any sophisticated planning application, to design versatility. In other words the expanded DeepGreen protocol ought to be:

• Open to multiple input so that urban stakeholders can interact with several layers of data and appreciate the effects of their hypothesis.

• Time based, to enable all stakeholders to appreciate the effects of new policies and strategies systemically.

• Visually compelling, thus enabling all stakeholders to visually appreciate the simulated urban form across several orders of scale.



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16 Reinterpretation of the munipal waste collection networks of Guatemala City using the GAN_Physarum algorithm; algorithm training based on Physarum Polycephalum behaviour.

17 Redefined morphology and materiality of two overlapping systems : local to municipal waste collection networks and the vegetation network in the city of Guatemala City; algorithm training based on Physarum Polycephalum behaviour.

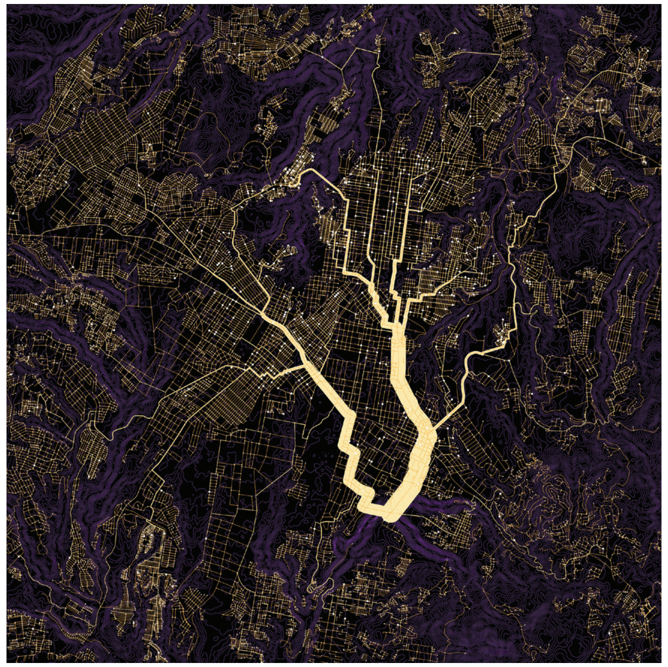
The design scenarios, which emerged from the study, suggest that a key remit for DeepGreen is to help breaking the currently uneven distribution of resources to promote the evolution of restorative urban systems. As previously observed, this process often implies questioning traditional planning concepts such as zone, boundary, scale, typology and program. Such outdated notions actually constrain the emergence of a truly systemic approach to urbanisation, one that recognises the nature of contemporary cities as complex dynamical systems and their interconnectedness with the larger Urbansphere.

This issue is most evident in the case of Guatemala City (Pasquero, Poletto, 2019). Guatemala City is situated on a complex and highly unstable terrain surrounded by mountains and volcanoes, some of which are still active. Its ecosystems, originally very rich in biodiversity, are now made fragile by unchecked urbanisation and, given its climatic zone, the effects of climate change. In Guatemala City this scenario is exacerbated by a serious lack of waste management. The Guatemala City garbage dump is the biggest landfill in Central America containing over a third of the total garbage in the country. 99% of Guatemala's 2,240 garbage sites have no environmental systems and are classified as "illegal." Confronted with this scenario, the authors have come to realise that only a design methodology powered by dig data gathering and the production of ad hoc algorithmic design scenarios can deal with such complexity and level of informality.

The DeepGreen protocol facilitates the creation of an interface between bottom up processes of self-organisation, such as the many local waste recycling activities (Fig.13) that are emerging out of necessity in the areas closer to the dumping sites, and the strategic decision making that occurs at municipal, national and international level. The aim is to find new synergies and direct investments where and when they have the most potential to engender positive change.

In DeepGreen the protocol to generate the urban datasets for GAN-Physarum is expanded in order to read and process several kind of input data. As described at the beginning of this paper it involves input data reading, biotic-abiotic analysis and network systems analysis.

In Guatemala City the authors refer to 3 kind different kinds of remote sensing data: land survey (at a resolution of 10m), Digital Elevation Models (at a resolution of 30m from the NASA database) and GIS vectorial data from the Open Streep Map project. These datasets are processed at a resolution of 1m over a frame of 16km comprising the entire city centre and several peripheral neighbourhoods. Municipal, local and informal waste disposal and recycling sites are mapped and their location marked. The existing road network (Fig.14, 15) is also mapped and all potential



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18 Local to municipal waste collection networks in the city of Guatemala. Image algorithmically computed from GIS map, satellite map and DEM model analysis by means of minimal path algorithm. The analysis also takes into account the result of the local waste collection analysis. Iteration 1

19 Biotic network analysis for the city of Guatemala. Drawing of the proximity network of existing biotic systems, highlighting areas lacking connectivity and requiring re-greening, overlapped with waste collection network

sources of waste are located over it. Two sets of path systems are then computed: local path systems connect all waste sources with the closest dumping sites. Municipal path systems connect all dumping sites with six proposed municipal recycling centres. All paths are thickened and colour coded depending on the amount of waste that travels on each of their branches. The process is repeated for different kind of waste, organic, metal, paper and plastic. The emerging diagrams (Fig.18,19) are fed to GAN_Physarum as urban datasets.

Two radical visions define the case of Guatemala City. On the one hand the waste infrastructure appears as a biologically active, convoluted and highly differentiated body, capable of sorting, transporting and re-metabolizing the urban waste into nutrient and raw matter. On the other, GAN_Physarum reimagines Guatemala City as a networked body gently suspended over a wild substratum of proliferating biological life (Fig.16, 17). Once shared with a wider group of stakeholders these visons have triggered a more concrete set of proposals among which two are finding significant traction. A re-wilding plan to foster new coexistence between human and urban wild animals, and an urban agriculture plan proposing a method to guarantee food security and recycle organic waste while employing the rural population currently migrating to the city of Guatemala.

What matters to the authors is that both proposals are sensitive to local conditions while effecting international power relationships. For instance, the migrating birds populating the green areas of Guatemala City migrate to and from Canada. Therefore, investments in urban re-wilding will have benefit in the biodiversity of Canada too. Migrant workers cross the city on their way to the US-Mexico border. Urban agricultural plans could retain rural workers alleviating the pressure on both Mexico and the US. Such synergies have the potential to channel significant international funds to local projects improving the life of citizens of Guatemala City.

Conclusions

From the testing conducted so far, it emerges that high resolution in the generation of analytical datasets on both urban and biological case studies results in substantially more accurate scenario modelling. It is known that contemporary cities share unique emergent behaviours and self-organizing growth patterns with organisms like Physarum Polycephalum therefore the DeepGreen method has the potential to evolve into an effective urban planning model. However this requires a design protocol capable of generating input datasets that can achieve a resolution of about 10m across the entire study frame in the urban domain, and of 1mm across the entire study frame in the biological domain.

Furthermore the quality of these datasets needs to be visually recognisable in the structure of the images. Particular attention must go to the tonal patterns of colour and to the gradients of luminosity. Such patterns must be consistent across the entire image frame to avoid areas featuring lack in informational clarity. The presence of such areas can affect the efficacy of the training process and therefore negatively affect the results of testing. While further testing is necessary to confirm widespread applicability and considering that the developed of DeepGreen is an ongoing research effort for the authors and their team, at its core lies the potential to capture the proven intelligence of Physarum Polycephalum, emergent, distributed and embodied, to design cities capable of searching for the opportunities of co-evolution within the expanded urban landscape. Cities that can find untapped resources and re-metabolise their waste while minimizing the expenditure of energy required to accomplish these fundamental survival tasks.

A city made by humans, for both human and non-human citizens and planned by a new form of in-human intelligence.

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Pasquero Poletto that there is for 2019 : Beauty as Ecological Intelligence: Bio-digital Aesthetics as a Value System of Post-Anthropocene Architecture

Eames: https://www.eamesoffice.com/education/powers-of-ten-2/

debord: https://www.cddc.vt.edu/sionline/si/theory.html

IMAGE CREDITS

Image 01 and 06-12: created by ecoLogicStudio with The Synthetic Landscape Lab at Innsbruck University and The Urban Morphogenesis Lab at the Bartlett UCL, 2020. Lead Researchers: Dr. Claudia Pasquero, Dr. Marco Poletto. Project team: Eirini Tsomokou, Korbinian Enzinger, Joy Boulois, Oscar Villareal.

Images 02-04 and 13-19 created by ecoLogicStudio with Innsbruck University and The Bartlett UCL for UNDP.

Image 05: - Physatopia project_by Rc16, The Bartlett UCL 2018. Tutors: Dr. Claudia Pasquero with Filippo Nassetti, Emmaouil Zaroukas.Students: Qin Qing, Jia Itu.

Claudia Pasquero is an architect, curator, author and educator. She is founder and co-director of ecoLogicStudio in London, Lecturer and director of the Urban Morphogenesis Lab at the Bartlett UCL, Professor of Landscape Architecture and founder of the Synthetic Landscape Lab at Innsbruck University. Claudia has been Head Curator of the Tallinn Architectural Biennale 2017, and she has been nominated in the WIRED smart list in the same year. She is co-author of "Systemic Architecture - Operating manual for the self-organizing city" published by Routledge in 2012. Her work has been published and exhibited internationally.

Marco Poletto is co-founder and Director of ecoLogicStudio and the design innovation venture PhotoSynthetica, focussed on developing architectural solutions to fight Climate Change. Marco holds a PhD Degree from RMIT University, Melbourne. He is also co-author of "Systemic Architecture" a book published by Routledge in 2012. Marco's work has been exhibited internationally, more recently in Paris (Centre Pompidou, 2019), Tokyo (Mori Gallery, 2019), Vienna (MAK, 2019), Karlsruhe (ZKM, 2019) and Astana (EXPO 2017).